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Low-Cost of Fix-Wing Prototype Using Zimmerman Design

Ya'akob Mansor[1,2,*], Sharudin Omar Baki[1], Ikhwan Syafiq Mohd Noor[1], Emma Ziezie Mohd Tarmizi[1], Nor Azah Abdul Aziz[1], Zulhilmy Sahwee[3]

[1] Physics Unit, Centre of Foundation Studies in Agriculture Science, Universiti Putra Malaysia (UPM),43400 Serdang, Malaysia
[2] Institute of Plantation Studies, Universiti Putra Malaysia (UPM), 43400 Serdang, Malaysia
[3] Universiti Kuala Lumpur, Malaysian Institute of Aviation Technology (MIAT), 43800, Dengkil, Selangor, Malaysia

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ABSTRACT

This paper discussed the design and development of a fix-wing UAV that uses a Zimmerman parameter. To increase structural strength, a material made of expanded polypropylene and expanded polystyrene was used. Using a bagging vacuum technique for 24 hours, the structural strength procedure thoroughly combines the resin and fiber. The Zimmerman graph, generated at speeds between 50,000 and 200,000 using Reynolds Numbers (RE), was analyzed using three key variables: the coefficient of lift, drag, and the angle of attack (Alpha) of the airfoil. At 10°, the airfoil started to stall based on indicated coefficient used. The test flight is also comprised of pitch and roll flight with adequate force and little overshoot between the autopilot's requirement and the small aircraft's actual performance.

1. Introduction

A radio-controlled transmitter is used by a ground operator Unmanned Aerial Vehicle (UAV) to control the aircraft. They can be divided into two primary groups: rotary-wing aircraft and fixed-wing aircraft. Based on how each design functions, these two are distinguished from one another. In contrast to fixed wings, which produce lift via the wing's aerodynamic form, rotary wings depend completely on their rotor for lift [1-6].

A flying wing configuration is a fixed-wing UAV design that excludes a tail and no definite fuselage. From a streamlined and auxiliary weight perspective, this design is the most efficient. The high lift-to-drag ratio of flying wing configuration is another benefit [7]. A flying wing design potentially boosts its lift-to-drag ratio by roughly 20% when compared to a conventional design [8]. Multi-rotors, which have a similar size and weight as rotary UAVs, are more stable, able to carry a larger payload, and are secured against a system crash. Fixed-wing UAVs can typically hover in the air for a long

* *Corresponding author.*
E-mail address: yaakobms@upm.edu.my

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period, allowing them to traverse through a broad region and even access the airspace above [9,10,11].

Therefore, this research aims to create a fix-wing platform that may be used as a VTOL (Vertical Take-off and Landing) flying such tractor and pusher propeller wings to reduce parasitic drag. Low-cost UAVs as relatively inexpensive and readily available. Spare parts are available from alternative brands, open-source hardware, and software that is supported through community groups, easy to attach sensor payloads without alternating the body and require a short time to set up [12].

2. Methodology

The wing design and airfoil are the main components of this model. This model's Computer Aided Design (CAD) was created with Computer Aided Three-Dimensional Interactive Application (CATIA), and Figure 1 shows a sketch of the model [13].

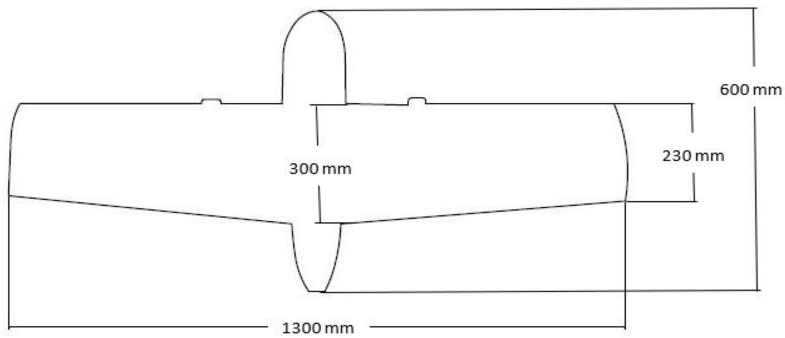

Fig. 1. CAT CATIA of UAV model

2.1 Wing

This wing platform adopts a Zimmerman wing design [14] including the wing root and wing tip chord together with wing loading, for the best-performing wing planform for small UAVs.

The ratio of tip over root (taper) was 0.76, where the 300 mm root chord and 230 mm tip chord is used in the UAV's design. By utilizing taper ratios between 0.3 and 0.79 [15], the lift coefficient will increase maximum.

Another crucial consideration while developing the UAV wing is the wing's aspect ratio. The aspect ratio is the wingspan divided by the length of the wing chord. Aspect ratios between 3 and 6 are most frequently utilized for small, remote-controlled aircraft. Given that the UAV's wingspan is 1300 mm, and its mean chord length is 265 mm, the aspect ratio calculation yields a value of 4.91 as shown in Figure 2, still in the small UAV aspect ratio range [16][17].

The wing loading parameter is a crucial consideration while designing the wing. Wing loading is calculated by dividing the aircraft's total weight by the area of its wings. The aircraft's stalling speed is determined by wing loading. The wing loading for this aircraft is 4.6 kg/m^2, which falls into the small UAV type, which flies at a slower speed and low stall angle. Wing parameters are shown in Table 1.

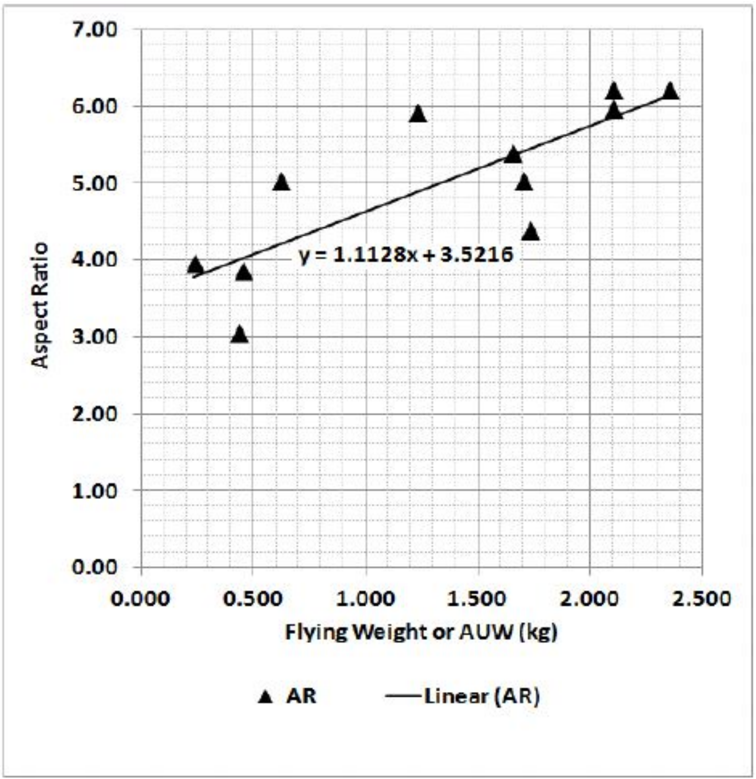

Fig. 2. Small UAV Aspect Ratio

Table 1
Wing parameters prototype

WING	RESULTS
Flight Platform	FIX-WINGS
Root	0.30 m
Tip	0.23 m
Aspect Ratio	4.91
Span	1.30 m
Loading	4.6 kg/m^2
Maximum Altitude	250 m
Payload	500 g
Approximate Flight Time	60 minutes
Easy Of Use	Easy

2.2 Airfoil

The cross-sectional form of a wing is known as an airfoil. The leading edge of the airfoil is the part that is perpendicular to the lower and upper surfaces, while the trailing edge is the part that is attached to the back of the airfoil. The choice of the airfoil has a significant impact on how well the aircraft performs. The shape of the airfoil directly affects the lift force that the wing generates. As a result, choosing an airfoil necessitates both extensive experimentation and significant computational work.

The MH 60 cross-sectional shape parameters are suitable for small fix-wing designs based due it has structural strength thickness ratio (10.08 %). Additionally, its aerodynamic shapes generate a lift and drag polar ratio at 0^{o} of the angle of attack with a positive moment coefficient [18].

Consequently, this airfoil was selected for this project. To address the longitudinal stability problem associated with flying wing design, reflex airfoil shapes like the MH60 can be used. In their study, Ashfar et al. discovered that the reflex section's positive angle creates a downward force of air on top of the wing that will decrease and enhances stability [19,20]. Figure 3 shows the MH60 airfoil's detailed dimensions.

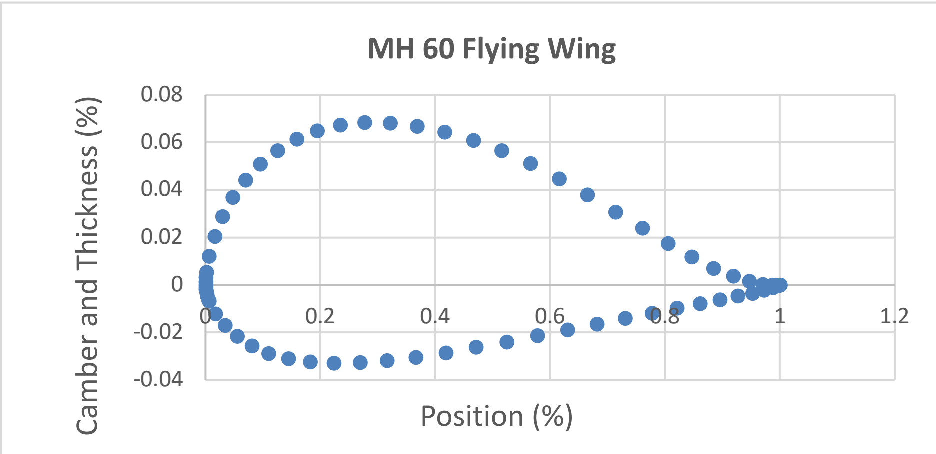

Fig. 3. MH60 Airfoil

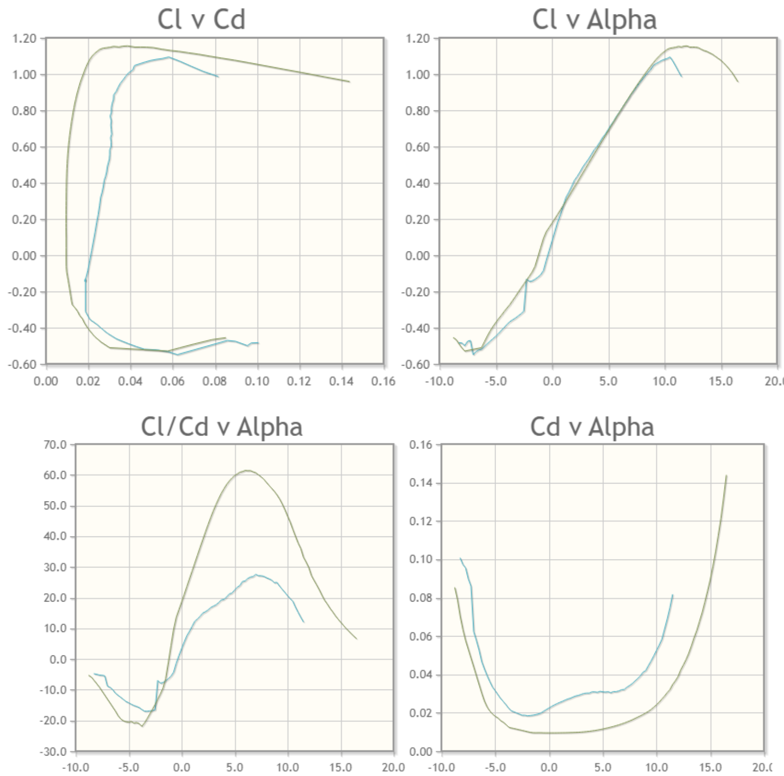

Fig. 4. MH60 Airfoil Polar Plot

The variables for the analysis of the graph are the coefficient of lift (cl), the coefficient of drag (cd), and the angle of attack (Alpha) of the airfoil. The lift/drag polar of the MH60 airfoil's results is shown in Figure 4, where the graph was drawn at speeds between 50,000 and 200,000 Reynolds Numbers (RE), which correspond to the range of flying speeds for the UAV. This airfoil has the lowest drag when operating within the Cd range of 0.02 to 0.10. While having a maximum Cl of roughly 1.2, the Cl vs Alpha plot shows a stall at an angle began of more than 10^{o}, and best to fly the UAV at an angle of 60^{0}.

3. Prototype

Expanded polypropylene (EPP) and expanded polystyrene (EPS) foam, which contains 98% air and 2% material are used as the basic material to construct the prototype from scratch. According to Ariyanto et al., using this material for UAV manufacturing provides several benefits including ease of manufacture, low material cost, and lightweight structure [21].

This material's low structural strength, however, was addressed by using an advanced composite method approach to increase structural strength. By completely fusing resin and fiber composite, this technique increases structural strength. A CNC cutter was used to manufacture the prototype's wing and fuselage sections, which can fabricate both tapered and straight shapes. Based on the CAD, this machine melts the foam material using a temperature-controlled wire. EPP foam with low density and high elasticity properties and suitable for absorbing landing impact was used for the fuselage section. Since it is lightweight and versatile but brittle and susceptible to deformation, EPS foam is utilized for the wing portion.

To add reinforcement to the structure, fiber composite material is used. A vacuum bagging procedure is used to cure the fiberglass cloth-wrapped EPS core. The vacuum bagging method, as seen in Figure 5, aids in increasing the strength and rigidity of the wing surface while also smoothing off the surface. The fiberglass and foam core were joined together using epoxy resin. The wing had to cure for 24 hours before it could be taken out of the vacuum bag.

Fig. 5. Vacuum bagging of the wing

4. Results

Any design for an aerial vehicle must undergo a flying test to provide the final validation of the design. To determine the stability of the proposed and produced flying wing design, a flight test was undertaken for this study. The manual flight mode was used for the initial flight tests and changed to automatic mode after the controller had been adjusted for level flight to test the aircraft's response to pitch and roll motion.

This airfoil has the highest Cl/Cd at an angle of 6 degrees, based on the Cl/Cd vs. Alpha plot results. Based on this information, it is recommended to fly the aircraft during the cruising phase at a 6-degree angle. Based on the most recent Cd vs. Alpha polar plot, the ideal angle for minimizing drag is between -5 and 9 degrees.

The electronic flight component is installed on the prototype in preparation for flight testing. The flying controller for this prototype is PIXHACK version 2.8.4, which uses Arduplane firmware. Two SunnySky 1100kv motors with 9x6 nylon propellers are used in the propulsion system to produce the necessary thrust for the UAV. A 6300 mAh lithium-ion battery powers it. The first flight test was conducted with a twin-rotor configuration. The test flight included the recording of all flight data, including sensor and aircraft parameters. The software Mission Planner is used to examine this flight data mission.

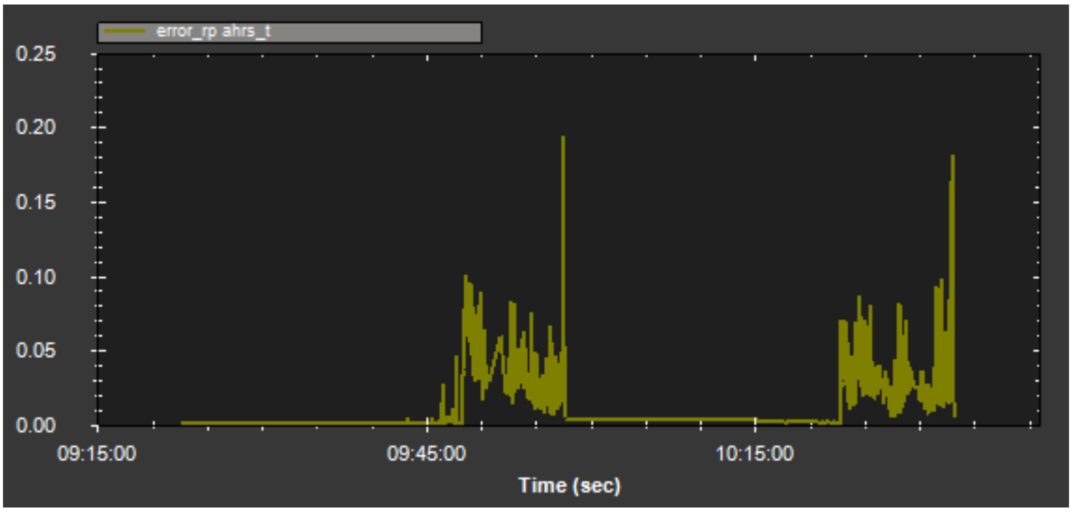

Fig. 6. UAV Pitch and Roll response

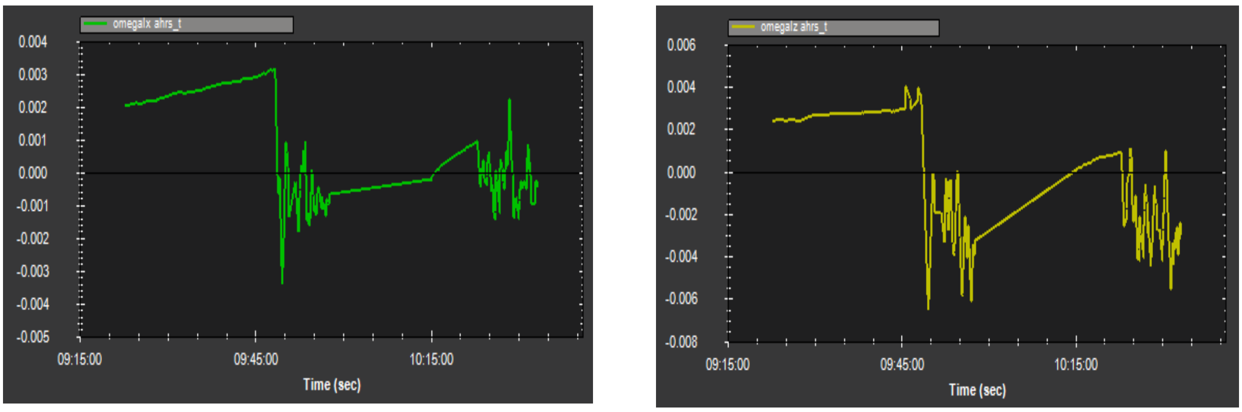

Fig. 7. UAV roll and a pitch angle

The combination of the aircraft's pitch and roll during the flight is shown in Figure 6. Results are good as they are still in the standard range of 0.1 and 0.4, and the increment is 0.1 (unitless). With sufficient force and little overshoot, the aircraft responds to the autopilot's pitch request. The result shows that the UAV has sufficient thrust to lift off with a high-pitch angle.

Figure 7 shows the roll angle and pitch angle. The entire angles show the difference between the body and the control board. All the results are good as they are still in the range of -0.1745 +0.1745, with an increment of 0.01 (Unit Radians). This flight information provides better accuracy and reliability compared to the traditional system which is based on a gyroscopic instrument and airfoil selection.

The choice of the airfoil has a significant impact on the wing's performance. The shape of the airfoil directly affects the lift force that the wing generates. As a result, the airfoil selection results in the appropriate lift and drag ratio and positive moment coefficient at zero degrees angle of attack. The MH60 airfoil is used as the airfoil for flying wing design because its modest ratio of 10.12% provides structural strength.

4. Conclusions

A fix-wing prototype has been constructed in this study, with various factors have been examined. Due to their low cost and simplicity of usage throughout the manufacturing process, the core material is made of EPS and EPP. To achieve stable flight and ease of manufacture, this prototype combines the Zimmerman airfoil design as a high-wing arrangement for a small UAV. For UAV stability, a horizontal stabilizer and winglets were added to this prototype. The aircraft's roll and pitch stability are improved by this modification which can be altered into many configurations. The UAV prototype acquisition system includes pre-flight, problem diagnosis, component calibrations, and flight planning. Additionally, this research has successfully distributed typical block images uniformly along the route plan utilizing a fully autonomous mode from take-off to landing, which has enhanced aerial typical block images and precise flight planning issues.

The three options for where to place the wing on the fuselage are high, mid, and low wings. The best location is the high wing because it is simple to manufacture, offers the highest stability, has high propeller clearance, and is simple to launch. As a result, the design has been chosen with high wings. To overcome the longitudinal stability problem associated with flying wing design, the reflex airfoil shape MH60 can be utilized. Thus, we observed that the reflex section's positive angle will result in a downward force that will increase longitudinal stability.

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References
[1] Niethammer, U., S. Rothmund, U. Schwaderer, J. Zeman, and M. Joswig. "Open source image-processing tools for low-cost UAV-based landslide investigations." *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 38, no. 1 (2011): C22. https://doi.org/10.5194/isprsarchives-XXXVIII-1-C22-161-2011

[2] Alvarado, Miguel, Felipe Gonzalez, Andrew Fletcher, and Ashray Doshi. "Towards the development of a low cost airborne sensing system to monitor dust particles after blasting at open-pit mine sites." *Sensors* 15, no. 8 (2015): 19667-19687. https://doi.org/10.3390/s150819667

[3] Villa, Tommaso Francesco, Felipe Gonzalez, Branka Miljievic, Zoran D. Ristovski, and Lidia Morawska. "An overview of small unmanned aerial vehicles for air quality measurements: Present applications and future prospectives." *Sensors* 16, no. 7 (2016): 1072. https://doi.org/10.3390/s16071072

[4] Watts, Adam C., Vincent G. Ambrosia, and Everett A. Hinkley. "Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use." *Remote Sensing* 4, no. 6 (2012): 1671-1692. https://doi.org/10.3390/rs4061671

[5] Gonzalez, Felipe, Marcos PG Castro, Pritesh Narayan, Rod Walker, and Les Zeller. "Development of an autonomous unmanned aerial system to collect time-stamped samples from the atmosphere and localize potential pathogen sources." *Journal of Field Robotics* 28, no. 6 (2011): 961-976. https://doi.org/10.1002/rob.20417

[6] Bareth, Georg, Helge Aasen, Juliane Bendig, Martin Leon Gnyp, Andreas Bolten, András Jung, René Michels, and Jussi Soukkamäki. "low-weight and UAV-based hyperspectral full-frame cameras for monitor-ing crops: spectral comparison with portable spectroradiometer measure-ments." *Unmanned aerial vehicles (UAVs) for multi-temporal crop surface modelling* 103 (7).

[7] Hamada, Ahmed, A. Sultan, and M. Abdelrahman. "Design, Build and Fly a Flying Wing." *Athens Journal of Technology and Engineering* 5, no. 3 (2018): 223-250. https://doi.org/10.30958/ajte.5-3-2

[8] Bolsunovsky, A. L., N. P. Buzoverya, B. I. Gurevich, V. E. Denisov, A. I. Dunaevsky, L. M. Shkadov, O. V. Sonin, A. J. Udzhuhu, and J. P. Zhurihin. "Flying wing—problems and decisions." *Aircraft design* 4, no. 4 (2001): 193-219. https://doi.org/10.1016/S1369-8869(01)00005-2

[9] Mansor, Yaakob, Shattri Mansor, Helmi Zulhaidi, Abdul Rahman Ramli, and Ajibola I. Isola. "Multispectral sensors calibration for lightweight UAV." In *IOP Conference Series: Earth and Environmental Science*, vol. 169, no. 1, p. 012033. IOP Publishing, 2018. https://doi.org/10.1088/1755-1315/169/1/012033

[10] Mansor, Yaakob, Shattri Mansor, Helmi Zulhaidi, Abdul Rahman Ramli, and Ajibola I. Isola. "CALIBRATION OF LIGHTWEIGHT THERMAL SENSOR FOR FULLY AUTONOMOUS UAV." *SCIENCE & TECHNOLOGY RESEARCH INSTITUTE FOR DEFENCE (STRIDE)* 181 (2018): 181.

[11] Mansor, Yaakob, Shattri Mansor, Helmi Zulhaidi, Abdul Rahman Ramli, and Ajibola I. Isola. "Development of lightweight and low-cost fully autonomous hexacopter UAV." *SCIENCE & TECHNOLOGY RESEARCH INSTITUTE FOR DEFENCE (STRIDE)* (2017): 187.

[12] Sørensen, Lars Yndal, Lars Toft Jacobsen, and John Paulin Hansen. "Low cost and flexible UAV deployment of sensors." *Sensors* 17, no. 1 (2017): 154. https://doi.org/10.3390/s17010154

[13] Yusuf, Siti Nurul Akmal, Yutaka Asako, Nor Azwadi Che Sidik, Saiful Bahri Mohamed, and Wan Mohd Arif Aziz Japar. "A short review on rans turbulence models." *CFD Letters* 12, no. 11 (2020): 83-96. https://doi.org/10.37934/cfdl.12.11.8396

[14] Moschetta, Jean-Marc. "The aerodynamics of micro air vehicles: technical challenges and scientific issues." *Internation Journal of Engineering Systems Modelling and Simulation* 6, no. 3/4 (2014): 134-148. https://doi.org/10.1504/IJESMS.2014.063122

[15] Güzelbey, İbrahim Halil, Yüksel Eraslan, and Mehmet Hanifi Doğru. "Effects of Taper Ratio on Aircraft Wing Aerodynamic Parameters: A Comperative Study." *European Mechanical Science* 3, no. 1 (2019): 18-23. https://doi.org/10.26701/ems.487516

[16] Tao, Luoyi, and G. Rajesh. "DESIGN OF RC AIRCRAFT." (2013).

[17] Ariyanto, Mochammad, Joga D. Setiawan, Teguh Prabowo, and Ismoyo Haryanto. "Design of a Low-Cost Fixed Wing UAV." In *MATEC Web of Conferences*, vol. 159, p. 02045. EDP Sciences, 2018. https://doi.org/10.1051/matecconf/201815902045

[18] Brandt, John, Ryan Neuland, and Nicholas VanDeRoer. "Design, build, and testing of a swept back free-wing aircraft." In *51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition*, p. 138. 2013. https://doi.org/10.2514/6.2013-138

[19] Afshar, Sepideh, Aghil Yousefi-Koma, Hossein Shahi, Donya Mohammadshahi, and Hesam Maleki. "Design and fabrication of a delta wing micro aerial vehicle." *International journal of Mechanics* 4 (2007): 51-58.

[20] Beng, Soo Weng, and Wan Mohd Arif Aziz Japar. "Numerical analysis of heat and fluid flow in microchannel heat sink with triangular cavities." *Journal of Advanced research in fluid mechanics and thermal sciences* 34, no. 1 (2017): 1-8.

[21] Sahwee, Zulhilmy, Aina Suriani Mahmood, Nazaruddin Abd Rahman, and Khairul Salleh Mohamed Sahari. "Flight testing of control allocation for elevator actuator fault in small UAV." In *2016 International Conference on Control, Automation and Information Sciences (ICCAIS)*, pp. 232-237. IEEE, 2016. https://doi.org/10.1109/ICCAIS.2016.7822466